precipitation. The graphs (fig. 8) show a fairly close relation between rainfall at Seattle and Honolulu, but the graphs for all Weather Bureau stations and for the high-level stations maintained by the United States Geological Survey in Hawaii show no such relation.

Hawaiian precipitation is also of the "showery" class, and heavy rains rarely last more than a few hours. The applicability of the general rule—that even in wet periods heavy downpours lasting a few minutes are interspersed with short periods of sunshine—varies considerably with the altitude and location. In the upper valleys, with few exceptions, showers are daily occurrences, even in dry weather, though on extreme leeward points showers are rare. On the high peaks, like Mount Waialeale and Puu Kukui, the mornings are usually clear and the afternoons and nights *very wet*.

ADDITIONAL METEOROLOGICAL DATA NEEDED BY ENGINEERS.

[Points on which more data or further study would be helpful, including rainfall distribution and intensity, precipitation and heavy floods, evaporation, vegetation, soil infiltration, temperature, run-off.]

By ROBERT E. HORTON, Consulting Hydraulic Engineer, Albany, N. Y.

[Reprinted from *Engineering News Record*, Mar. 27, 1919, pp. 614-616.]

Every experienced hydraulic engineer feels the need of additional meteorological data. First of all, there are far too few rainfall stations, and where the stations are reasonably close together group records should be studied to gain light for use where the stations are far apart. Periodic distribution of precipitation, rainfall intensities, flood flows, evaporation, the influence of vegetation, soil percolation, temperatures of the air and of the surfaces of both soil and water, and, finally, the broad general phases of run-off—all need attention. A brief review of the more important meteorological needs, grouped under 10 heads, follows:

1. *More stations.*—A much larger number of rainfall stations is needed throughout the country generally. In the East there is generally one station in each county, an average of about one station to every 1,500 square miles. In England, Denmark, Saxony, Jamaica, Barbados, St. Kitts, Victoria, and Mauritius there is an average of about one station to every 40 square miles. That is sufficient to provide good data for almost any small drainage basin, such as is commonly required for gravity water-supply systems. In New England the number of rainfall records available is about twice as great as elsewhere in the United States, owing to the fact that many good records are maintained in conjunction with water-works systems. But even in New England the number of stations is by no means adequate for satisfactory determination of the rainfall on many small drainage basins used for gravity water supply.

2. *Special group studies.*—In view of the sparsity of rainfall records, special groups of stations are needed, and studies based on existing data to determine the reliability, both of the long-term mean for any one station and the actual annual and monthly amounts indicated by single gages when applied over a varying radius of 1, 5, 10, or 15 miles from the station. Data are available at Providence, Worcester, Pawtucket, St. Louis, and New Orleans, where raingages are maintained sufficient in number to determine the general accuracy of a single record as applied to larger or smaller surrounding areas in those particular localities. Undoubtedly, with more data general relations could be established which would greatly increase the utility of rainfall records, and would also increase the degree of confidence which could be placed in such records where it becomes necessary to apply a single station to a considerable area.

3. *Periodic distribution of rainfall.*—Experience shows that with identically the same rainfall distributed in different ways throughout the year, especially during the summer, quite different amounts of run-off may result. In applying rainfall data, in critical cases, it is, therefore, necessary to take into account its distribution as well as its total amount. It is desirable, therefore, that the total number of rainfall days per month at each station should be published, with the amount of rainfall. For example: A rainfall of 4 inches in August may all occur in four days, with heavy thunderstorms, or it may be distributed throughout 10 or 20 days. In the latter case, the opportunity for water loss by evaporation would be enormously increased by the long-continued wetting of the ground surface, and the available supply for run-off would be steadier, but much smaller in amount than in the case of concentrated rainfall. I believe that practical methods can be readily developed by which the effect of rainfall distribution can be taken into account in estimating stream yield, if the number of rainfall days is known.

4. *Intensities.*—As regards rain intensity, there are at present about 200 stations in the United States with recording raingages. The details of these records, some of them running back to 1896, are published in the MONTHLY WEATHER REVIEW and in the annual reports of the Chief of the United States Weather Bureau. No complete, exhaustive analyses of all these records have ever been made. Partial analyses, covering the records within considerable areas, or for a considerable number of stations, have recently been made by Meyer and published in his "Elements of Hydrology," and by the United States Housing Corporation, the results not yet having been published. So far as the results go, they indicate that rain intensity formulas of the same type, but with varying coefficients, can be applied to localities having widely different amounts of rainfall.

Practice hitherto in using rain-intensity data in storm-sewer designing has been in general to work out a rain-intensity curve for each different place or problem. Usually, the data of the most intense and most critical storms are meager, and the results of such scattered individual studies are unquestionably less reliable than would be those obtained by thorough, general analyses involving a large number of stations of similar rainfall characteristics. There is room for much valuable work in standardizing and analyzing rain-intensity data along more general lines. Not only this, but all attempts hitherto to utilize such data have been wholly empirical. There is reason to believe that at least a semi-rational formula of general application can be developed for rain intensities of short durations.

5. *Great storms and floods.*—In connection with the broader problems of flood causation and flood discharge, studies of rain intensity in great storms covering periods of one to five days are needed. A valuable start was made in this direction by the Miami Conservancy District, the results being given in its series of technical reports, part 5. Good work along similar lines, with much more numerous records on which to base the results, has been done by the British Rainfall Organization.

One of the most fundamental problems of flood control is the determination of the relative frequency of occurrence of floods of different magnitudes, as fixing the maximum size and cost of works economically justified for flood control. Further data and analyses along these lines are much needed, and would be likely to afford results of broad utility and permanent value.

It may be noted in passing that so far as the studies by the Miami Conservancy District go, they seem to indicate that the law covering the relative magnitudes of storms of one to five days' duration, and having different intensities and frequencies of occurrence, is very similar in form to the general law covering the relations between frequency, intensity, and duration of short storms, such as are involved in storm-sewer designing—with, however, probably, the important difference that temporary storage of considerable volumes of rain by suspension in the upper air, in ascending air currents, is the important factor contributing to high intensities for rainfall duration of less than, say, one hour, but is not of importance in relation to storms of one or more days' duration.

Incidentally, there is a gap between existing results of studies covering, on the one hand, rain intensities used in storm-sewer designing and of generally less than one hour's duration, and flood intensities of one or more days' duration. This seems to open up a profitable field for investigation—a field which would be very likely to lead to results useful in both classes of studies. Furthermore, in many flood problems and in numerous litigations involving rainfall, the only data available are daily rainfall records. Data and studies showing the relation between 24 hours' rain and the average duration and intensity for the actual portion of the day during which rain fell are much needed.

6. *Evaporation.*—With regard to evaporation, very good records are now being kept by the Weather Bureau and other Government organizations. It appears, however, that records obtained from the ordinary evaporation pan, say 3 feet square, are not directly applicable to broad water surfaces. There is need for experimental determination of what may be called the area factor or average ratio of evaporation loss from a standard pan of a certain size to the evaporation loss from an area of any given size larger or smaller. A start along this line has been made in the work of Prof. F. H. Bigelow, R. B. Sleight, and others.

The writer, in Engineering News-Record of April 26, 1917, page 196, has called attention to the physical factors underlying and controlling this so-called area factor. The area factor involves, however, certain climatic conditions, especially convective action, data for which are not included in meterological reports. In view of the complexity of the subject, further studies, especially out-of-door experiments with evaporation pans of various sizes, are greatly needed.

In this connection, too, attention may be called to the need of further data and studies on the relation of altitude to evaporation. There is a prevailing popular notion that evaporation increases with elevation. This idea is undoubtedly derived from the well-known fact that water boils more readily at high than at low altitudes. This, however, is only one of the elements involved. Mean temperature at the surface decreases on the average about 1° for 300 feet elevation. The absolute humidity also decreases with elevation, in accordance with the exponential law developed by Hann. Wind velocity generally tends to increase with increased elevation. The amount of evaporation from water surfaces is mainly controlled by temperature, humidity, and wind velocity, and is affected probably to a minor extent by other factors, including so-called radiation or black-bulb thermometer temperatures, facility for convection, and barometric pressure. Some of the factors tend to cause an increase and others tend to cause a decrease in the amount of evaporation with increasing altitudes. The natural result would be the occurrence of some particular elevation for which evaporation losses would be [at a] maximum. While this fact never seems to have been pointed out before, yet it is confirmed by the few good observations available, especially those of Charles H. Lee. The whole subject of relation of evaporation loss to elevation is worthy of further investigation and more rational discussion.

7. *Vegetation.*—The subject of interception of rainfall by vegetation will be seen to be one of great importance, when it is considered that oftentimes, especially in light showers, 50 per cent or more of the rain is caught upon and directly evaporated from trees or other vegetation and never reaches the ground. This subject has been experimented upon in Europe, and to a limited extent in United States by the writer, and, I believe, also by the United States Weather Bureau. Further investigation and discussion would aid in laying a foundation for more rational estimates of stream flow and better determinations of water requirements for irrigation purposes.

8. *Infiltration.*—Floods are mainly the results of direct surface run-off from heavy rains or melting snows. The direct evaporation loss during flood rains is usually only a very small proportion of the available supply of water. The difference in flood-discharging capacities of different drainage areas is, without doubt, more largely due to differences in the amount of water which can percolate into the soil during heavy rains than to any other one factor excepting rainfall itself.

Furthermore, infiltration of rainfall is the source of ground-water supply to streams, wells, and artesian horizons; yet, with the exception of some meager experiments by O'Meara and the writer, practically nothing has been done in this country relative to the determination of the amount of infiltration into different soils, on different slopes, and with different rates of rainfall. Numerous formulas for estimating maximum flood discharges have been evolved, but it does not seem possible to arrive at either a rational understanding of the causation of floods or the most reliable method of estimating probable maximum flood discharge without taking into account the amount of infiltration occurring during rains.

9. *Temperature.*—The most important factor affecting evaporation losses of all kinds is temperature. It is also an important factor in relation to floods as affecting the rate of melting of accumulated snow. Data for air temperature are generally available, but what is needed in relation to evaporation is the temperature of the soil and of water surfaces. Data on these subjects are meager. The obtaining and publishing of additional data of soil-surface and water-surface temperatures, and especially the correlation of such temperatures with air temperature, are matters which will become of increasing importance and value as the development and use of more rational methods of handling hydrologic problems progress.

10. *Run-off.*—The run-off or yield of a drainage basin is the difference between the precipitation on the drainage basin and the water losses due to evaporation of various kinds. The amount of evaporation from the soil surface is dependent upon the same factors which control evaporation from water surface and, in addition, it is dependent on the degree of saturation of the soil surface. Some experimental data in relation to the evaporation loss from soil surface with different degrees

of saturation have been obtained by Samuel Fortier (see Engineering Record of April 15, 1905, p. 430).

Additional experimental data along this line would be of the utmost practical and economic value, not only in relation to the ordinary problems of hydrology in estimating stream flow, but also in relation to irrigation, land drainage, and agricultural engineering in general. The writer has designated the ratio of the actual evaporation rate from a soil surface at any given time and with any degree of saturation to the evaporation rate from water or a saturated soil surface as the "evaporation opportunity."[1]

It so happens that in long periods of drought, when the evaporation rate from a saturated surface is highest, the evaporation opportunity from the soil surface decreases. It is a natural result of these opposing influences that there is some particular amount and distribution of rainfall in any locality for which the total evaporation loss from the soil is a maximum. Although this is important, the writer does not think that it has ever hitherto been pointed out. Strangely enough, it follows as a simple mathematical deduction from a number of existing formulas for calculating run-off and, furthermore, it is abundantly confirmed by experience, inasmuch as it will be found that if almost any long-term record of rainfall and stream flow is analyzed, and the results are plotted in terms of water losses against precipitation, the resulting water losses will have a maximum for an annual rainfall which generally lies between 45 and 75 inches in England and the eastern United States.

This calls attention to the fact that the older ideas and methods of expressing run-off as a percentage of rainfall are essentially fallacious, and if engineers are to justify public confidence with regard to their ability to predict safely the available yield of water-supplies, their work must, in the future, be founded upon the use of meterologic data now often ignored and upon more rational and detailed methods of analyzing and utilizing such data.

[1] "Relative evaporation" or "Evaporativity" might be a more suggestive designation. See MONTHLY WEATHER REVIEW, Jan. 1919, 47:30.—EDIT.

ELEMENTS OF HYDROLOGY.

By ADOLPH F. MEYER, C. E., Associate Professor of Hydraulic Engineering, University of Minnesota.

[John Wiley & Sons (Inc.), New York, 1917, pp. 487, 287 figs.]

This volume is a welcome addition to our knowledge of hydrology and its practical application. It was prepared for the use of professional men, teachers and students of engineering, and aims to set forth the fundamental data and considerations rather than to provide a text book.

After defining hydrology and its applications the author presents in Chapter II a résumé of the physical properties of the atmosphere with a more or less condensed account of the variations of the several meteorological elements, closing with a brief reference to the general circulation of the atmosphere as manifested in the winds. Chapter III is devoted to a consideration of water, its various states and properties. Chapter IV on precipitation is a very complete résumé of the essential facts concerning the occurrence of precipitation and its geographic distribution. The remaining chapters deal with evaporation, from land and water surfaces transpiration, deep seepage, run-off, stream-flow data, supplementary stream-flow data, and modification of stream flow by storage.

The book is unusually rich in illustrative material, drawn largely from Federal and State reports, from private sources, as well as from the author's original investigations.—*A. J. H.*

THE WEATHER AND DAILY STREAM FLOW FOR HYDRO-ELECTRIC PLANTS.

By J. CECIL ALTER, Meteorologist.

[Dated: Weather Bureau, Salt Lake City, Utah, Apr. 11, 1919.]

SYNOPSIS.—The important part played by daily weather forecasts in the problem of water regulation for hydroelectric plants in Utah is brought out in this paper. The writer compares this work with the daily prediction of water stages on eastern rivers. As many of the hydro-electric plant reservoirs are located at least 36 hours' travel (measured by stream flow) from the plants themselves, it is of great importance that weather conditions, particularly as regards precipitation, be accurately known 36 hours in advance. If, for example, rain is expected at the end of any given period of 36 hours the reservoir outlet can be closed and the precious water saved until needed. On the other hand, if a period of dry weather is expected to set in at the end of 36 hours, the outlet at the reservoir must be opened so that the plant will have an abundance of water. These conditions apply equally well to irrigation control.—H. L.

Daily weather forecasts and general meteorological data have for some time entered rather largely into the problem of water regulation for the 27 hydro-electric plants of the Utah Power & Light Co., in northern Utah, and southeastern Idaho, as managed by Maj. Cooper Anderson, superintendent of the power department. The general problem bears some analogy to the daily prediction of water stages on eastern rivers, but many additional factors require serious consideration.

All but four of the plants mentioned are located on the smaller streams coming out of the Wasatch Mountains, the flow of which can be relied upon for running the plants to machine capacity only in the flood time; this is from about March to early June, inclusive, when mountain snow is melting most rapidly, and when precipitation is normally heaviest. During the remainder of the year many of these plants are subject to greatly decreased output for want of water.

In summer and autumn the water supply from snow stores in the mountains reaches a minimum, and this is normally the period of lightest precipitation in this region. A sustained stream flow, ample for power production purposes, occurs in these months only when previous snowfall and current precipitation are abnormally heavy. In winter the tributaries are closed by ice with the first hard freeze, the frost gradually sealing the larger feeders, and finally the trunk stream if the weather be very severe.

It is essential that these scattering plants be operated as fully as possible, because of their nearness and convenience to purchasers of the power produced; and inasmuch as the company provides by far the greater percentage of all electricity used by the mining, smelting, interurban and street railway, sugar refining, city lighting, and other companies in this district, which includes Salt Lake City, Ogden, and probably a score of smaller towns, the demands for current are very exacting.